Overlap of Fractional Cloud for Radiation Calculations in GCMs: A Global Analysis using CloudSat and CALIPSO Data

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- conventional GCMs: *description of cloud overlap for unresolved cloud fields must be provided, via parametrization, to carry out, at least, radiative transfer calculations.*

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The need to consider cloud overlap structure depends on the genre of the GCM:

- conventional GCMs: *description of cloud overlap for unresolved cloud fields must be provided, via parametrization, to carry out, at least, radiative transfer calculations.*

- MMF-GCMs (global CSRMs): *cloud overlap ceases to be a parametrization issue and becomes a diagnostic variable*

Objectives

- **make a global assessment of cloud overlap**

  - using CloudSat-CALIPSO data

- **estimate global-average radiative sensitivity for overlap**

$$\frac{\partial F}{\partial \mathcal{L}^{*}_{cf}}$$

- **assess feasibility of a very simple overlap *parametrization***

Data

CloudSat-CALIPSO cloud-mask: Jan and Aug 2007

- http://cloudsat.cira.colostate.edu/data_dist/OrderData.php
- 2B-GEOPROF and 2B-GEOPROF-LIDAR
- *CPR_Cloud_mask* ; *Radar_Reflectivity* ; *CloudFraction*

  - cross-sections: 50, 100, 200, 500, and 1000 km

    - what best represents a GCM column (Astin + Di Girolamo 1999)?

    - ~37,000 columns/orbit... many thousands of samples

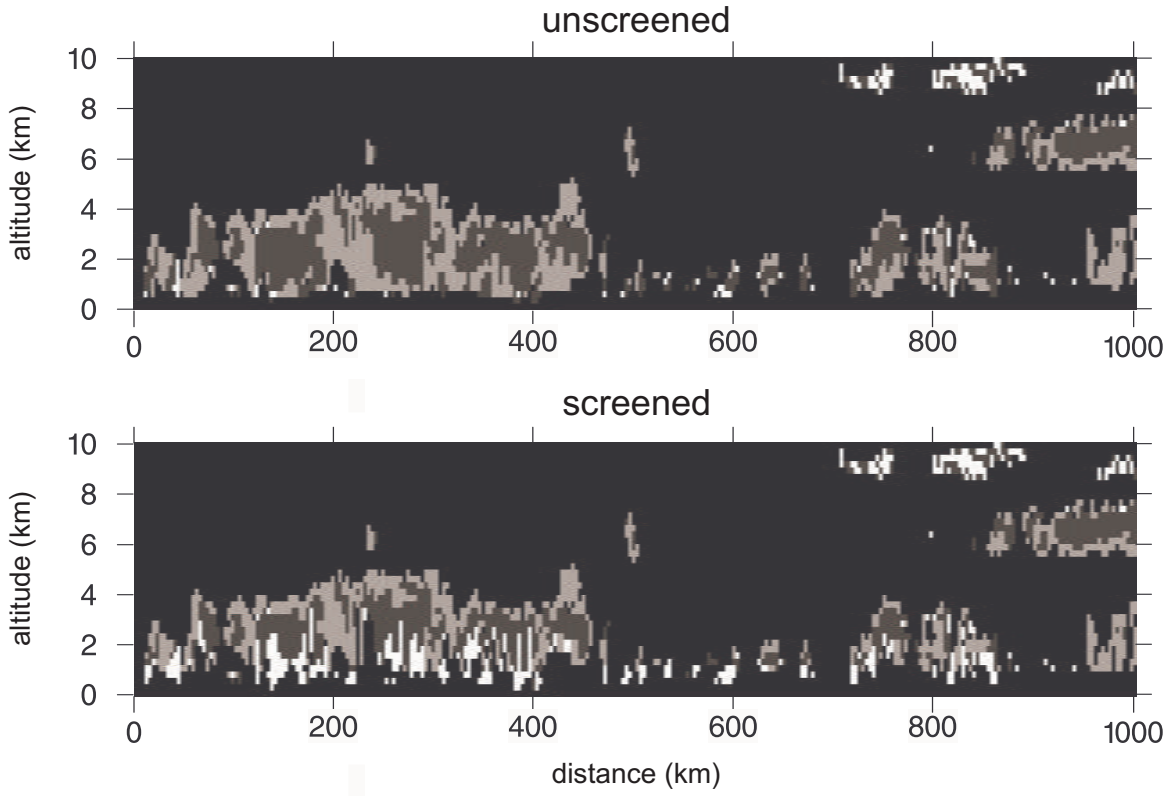
  - total cloud fractions $\in$ [0.05, 0.99]

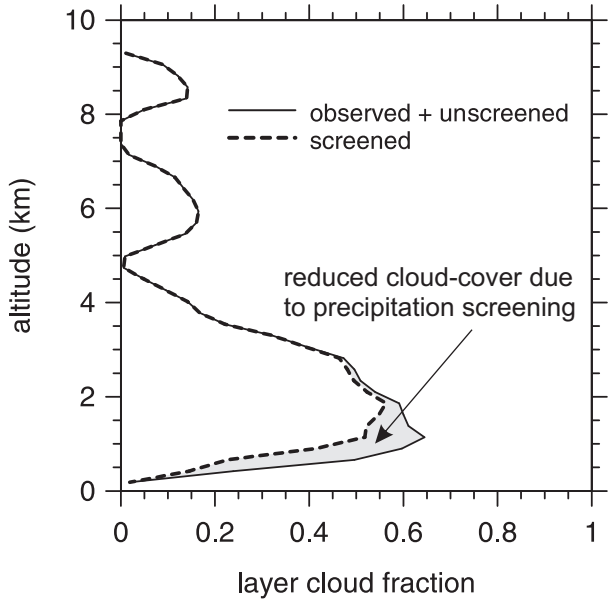
  - CloudSat's radar reflectivity ~ r^6... precipitation-mask???

precipitation-mask

"cloud" in bins 3 and 4 above the surface?

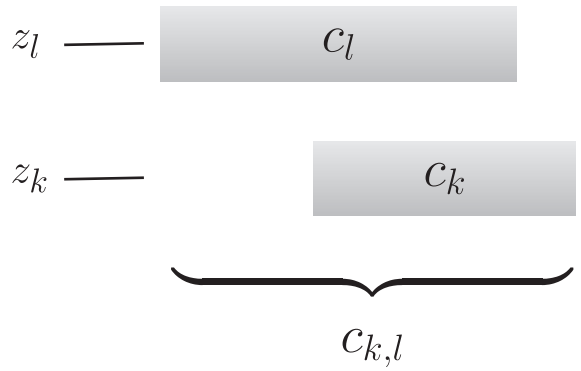
remove up to max(R) when lidar indicates no cloud





Methodology

Hogan and Illingworth (2000):



$$c_{k,l} = \alpha_{k,l} \underbrace{\max(c_k, c_l)}_{\substack{\text{maximum} \\ \text{overlap}}} + (1 - \alpha_{k,l}) \underbrace{(c_k + c_l - c_k c_l)}_{\substack{\text{random} \\ \text{overlap}}}$$

$$\alpha_{k,l} \equiv \exp\left[-\int_{z_k}^{z_l} \frac{dz}{\mathcal{L}_{cf}(z)}\right] \quad \Big| \quad \mathcal{L}_{cf}(z) \in [0, \infty) \; ; \; \alpha_{k,l} \in [0, 1)$$

$$c_{k,l} \in (\max(c_k, c_l), c_k + c_l - c_k c_l]$$

Effective Decorrelation Length

- assume $\mathcal{L}_{cf}$ does not vary vertically... unique $C(\mathcal{L}_{cf})$ given cloud fraction profile
- total cloud fraction $\widehat{C}$ from measurements
- using McICA's sub-grid cloud generator, solve:

$$\boxed{C(\mathcal{L}^{*}_{cf}) = \widehat{C}}$$

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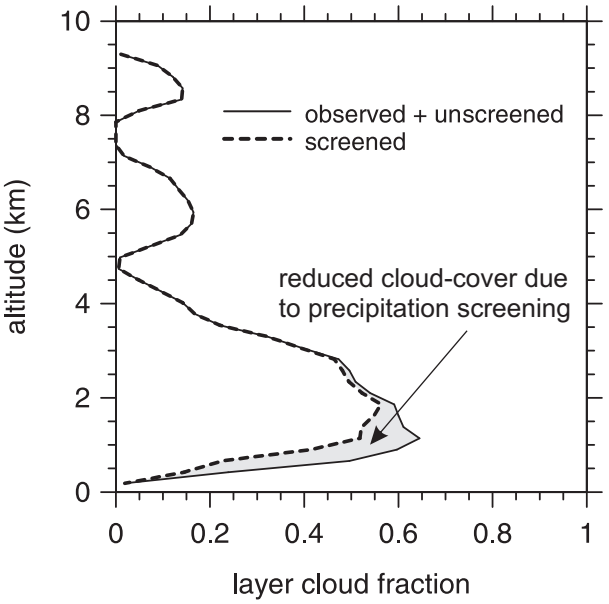
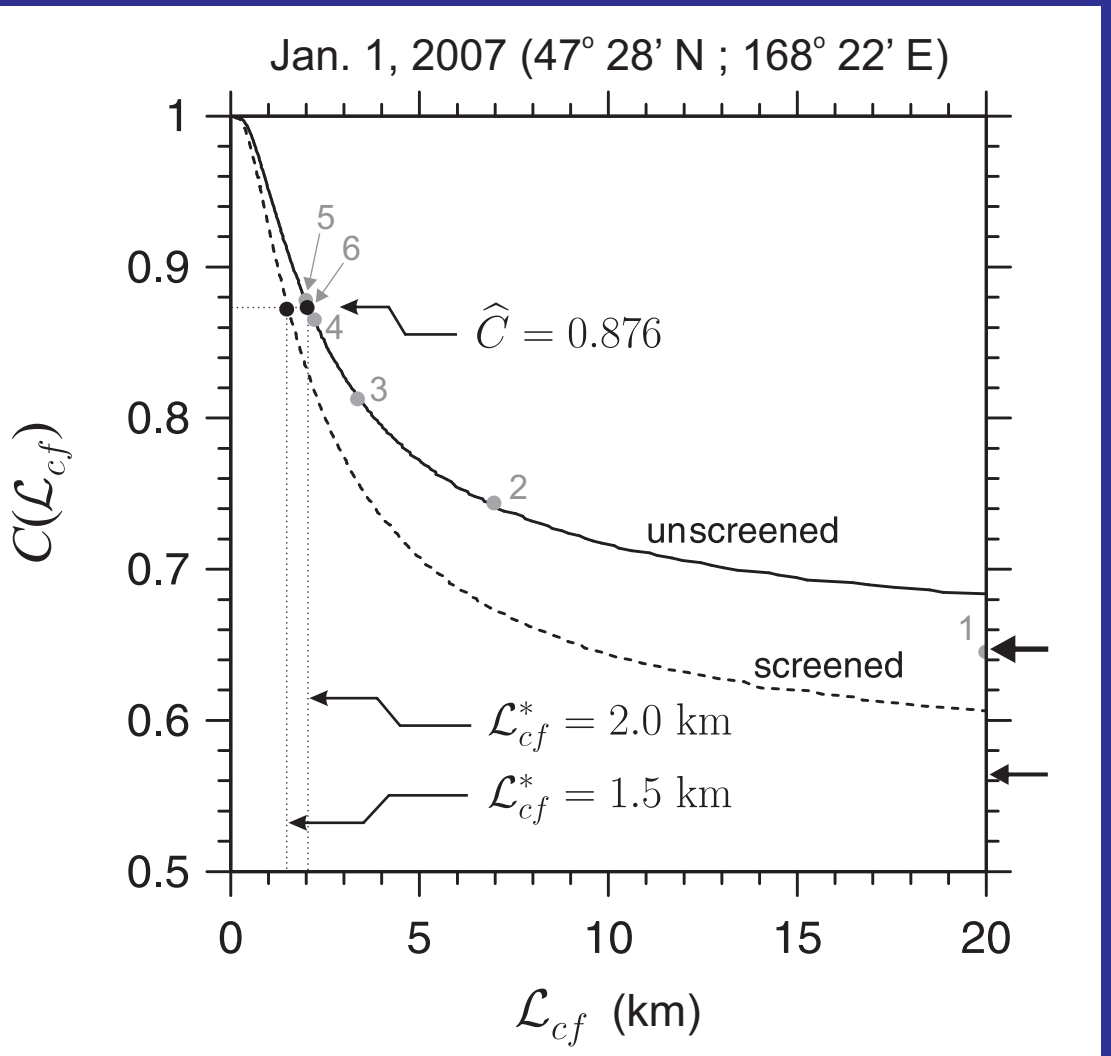
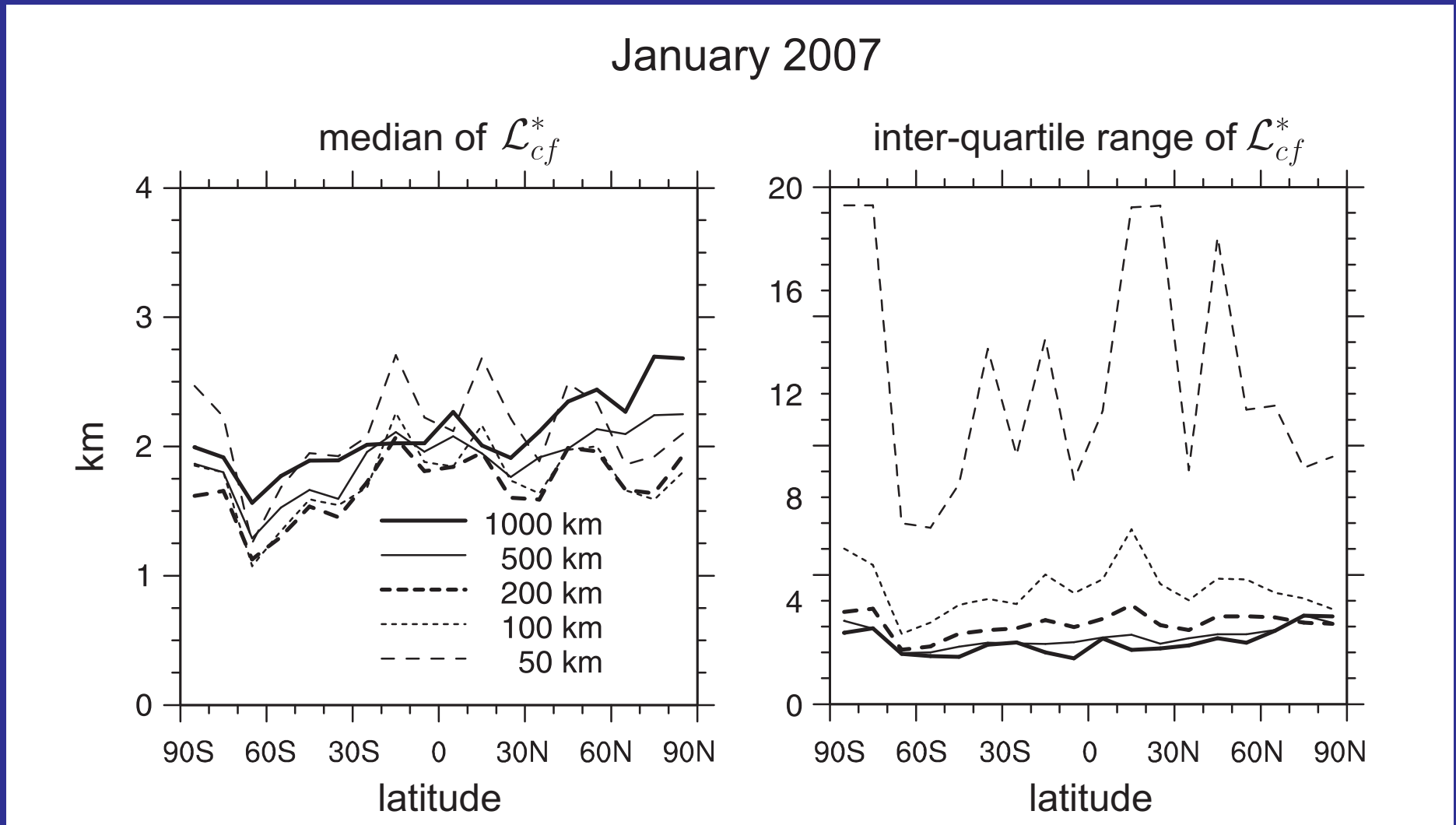




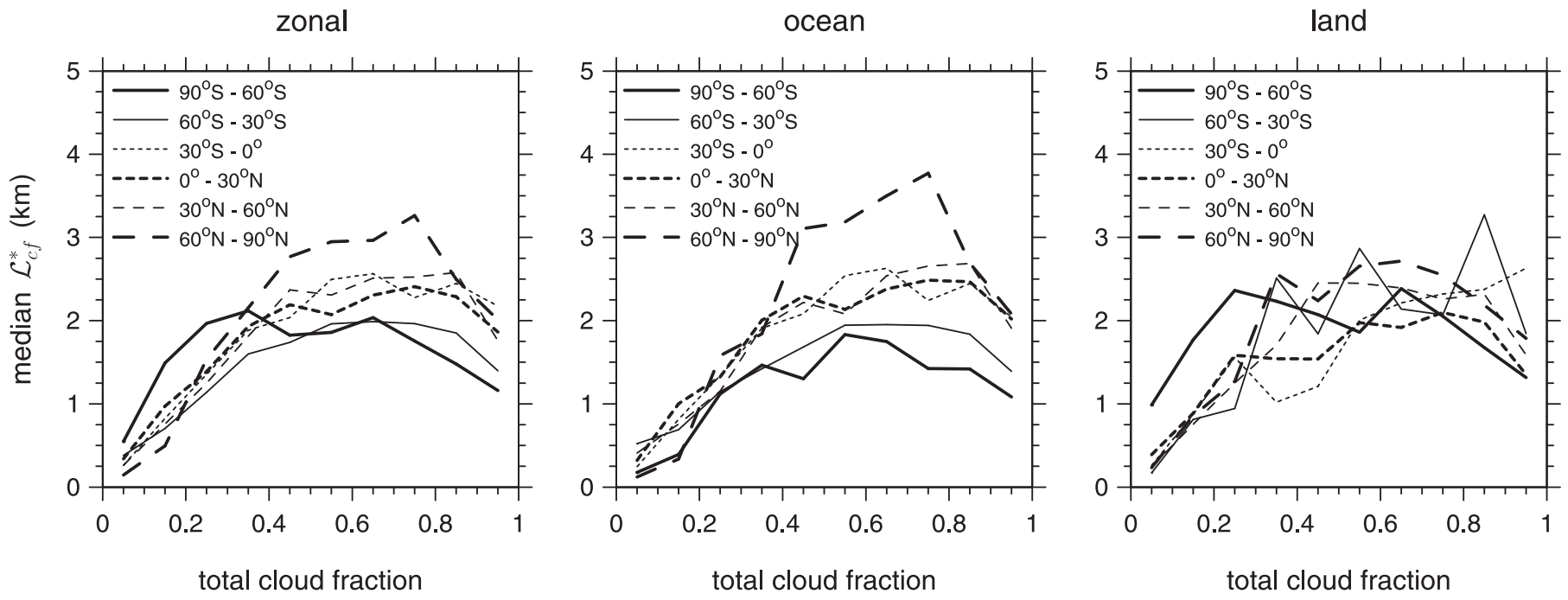


almost independent of cross-section length except for very small lengths

(scale-independent parametrization?)

500 km cross-sections

January 2007

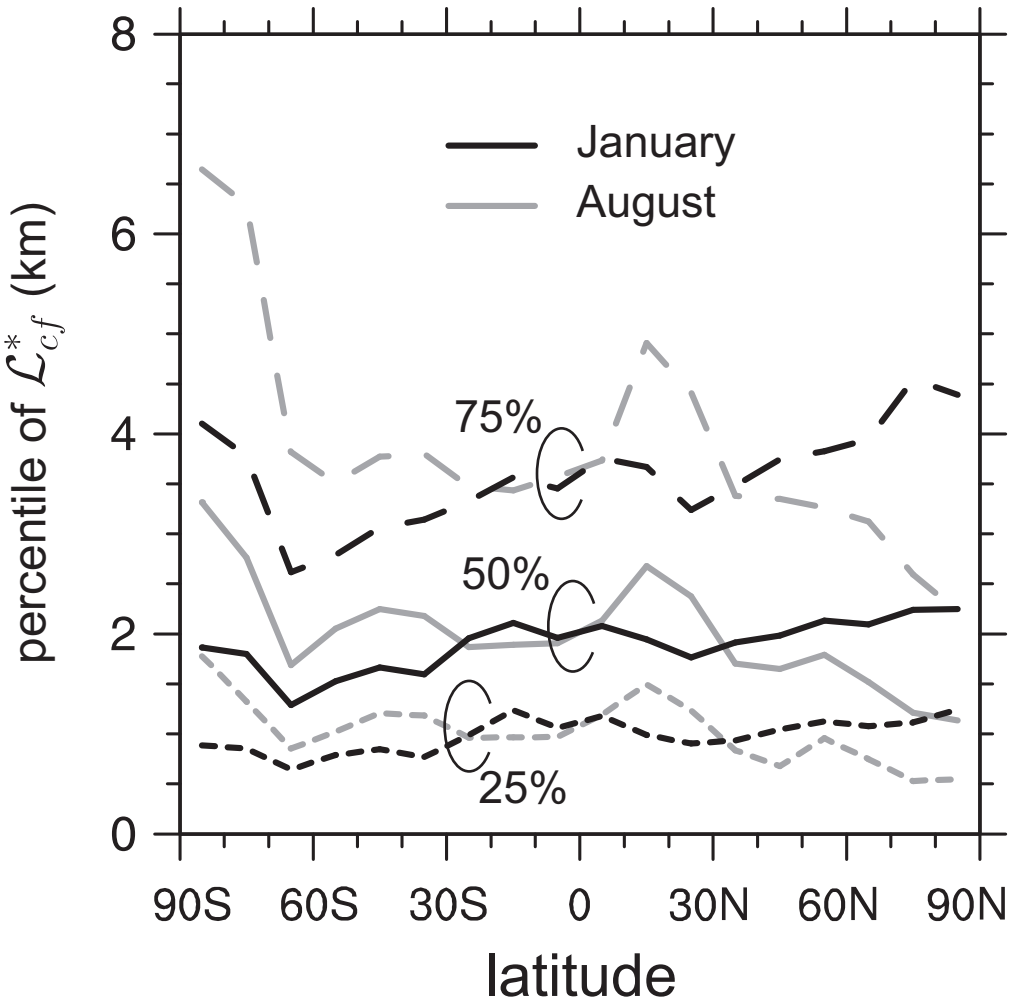


- little difference between land and ocean

- linear increase with C for small C

- peak medians of 2 to 3 km near C = 0.7

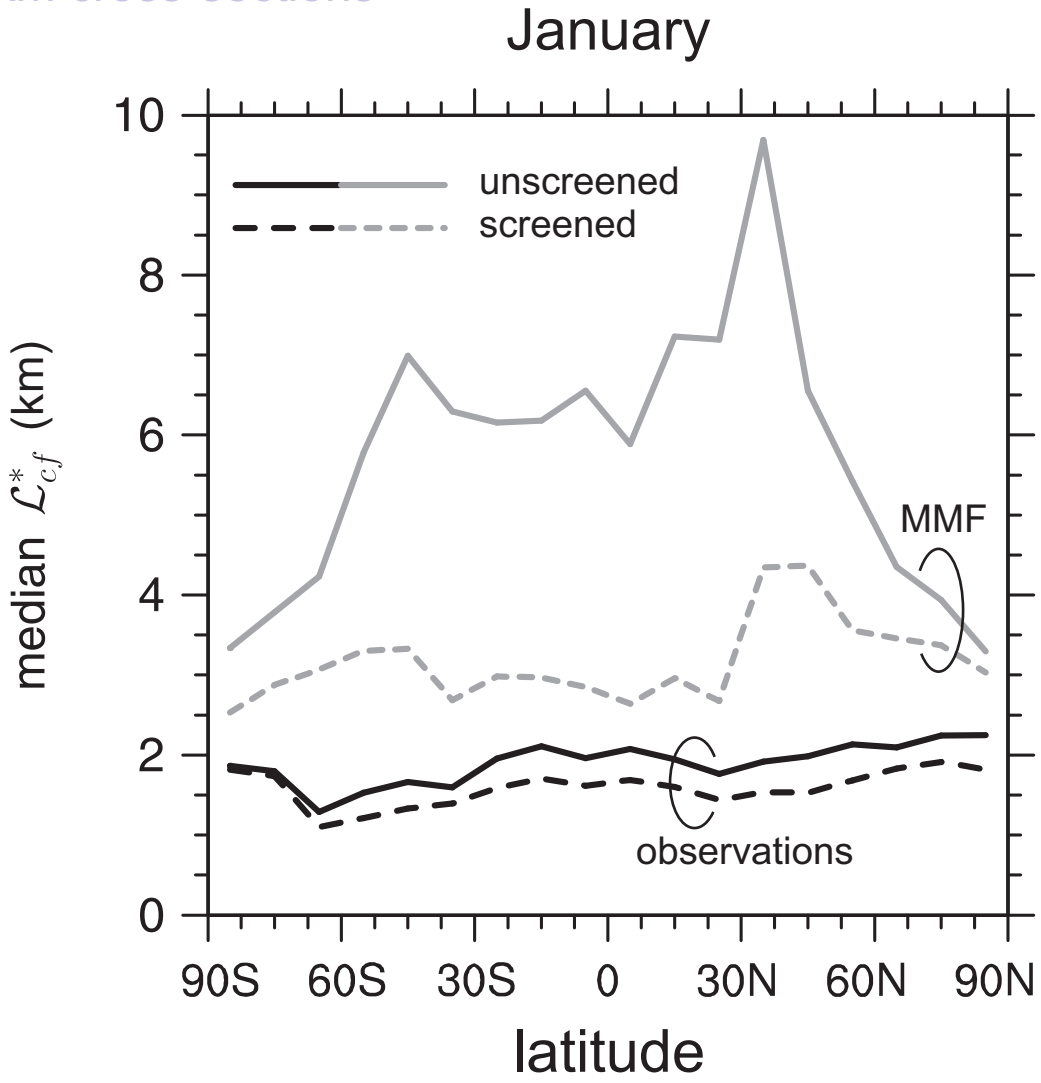
500 km cross-sections



largest values in Polar areas during winter and N. Tropics during boreal summer

- sedimentation of crystals and convection?

500 km cross-sections



- MMF values are very large (4 km grid-spacing vs. ~1.5 km?)

- screen for precip: minor for CloudSat, major for MMF

On the use of $\mathcal{L}^*_{cf}$ in GCMs

- is vertically-constant sufficient?
- how to set it?... not from total cloud fraction...
- how detailed need the parametrization be?
- is it something that changes with climate?...

$$F_{\mathrm{ICA}} = \int_0^\infty p(\tau)F(\tau)\ d\tau$$

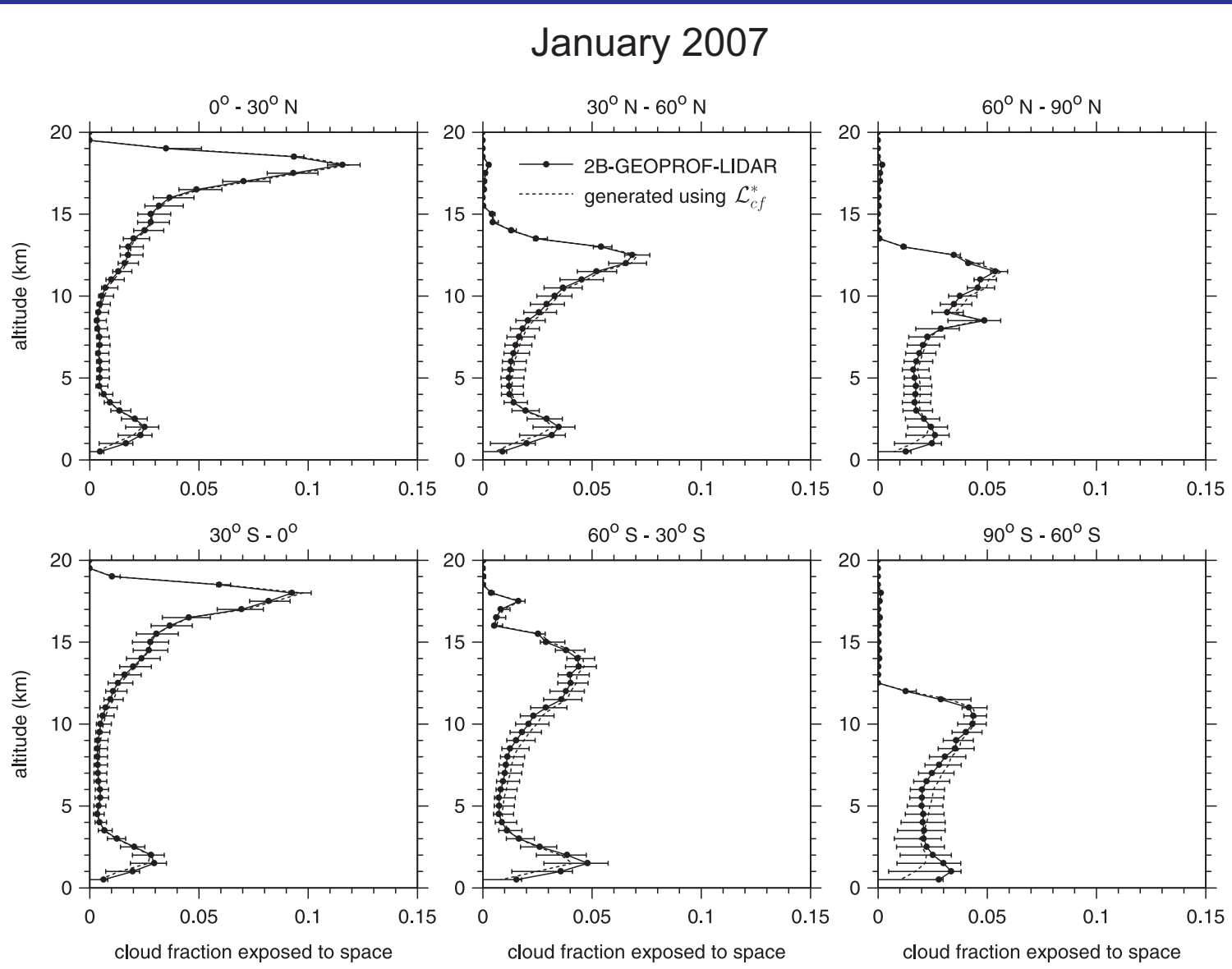
$$F_{\mathrm{ICA}} = (1-\widehat{C})F\left(0\right) + \widehat{C}\int_0^\infty \widehat{p}(\tau)F(\tau)\ d\tau$$

$$F_{\mathrm{ICA}} = (1-\widehat{C})F\left(0\right) + \sum_{m=1}^{M}\varepsilon_m \int_0^\infty \widehat{p}_m(\tau)F(\tau)\ d\tau$$

total cloud fraction

fraction of clouds in layer m with tops exposed to space

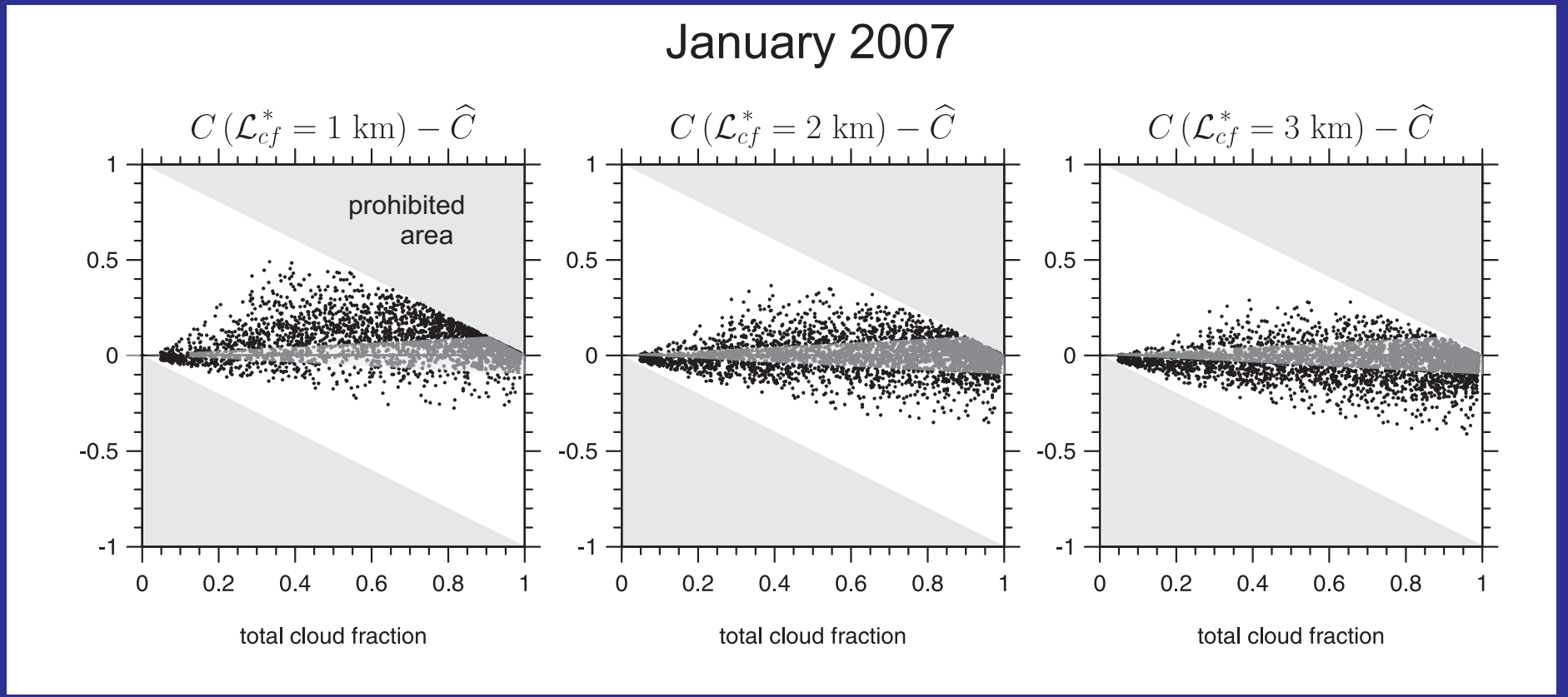
distribution of τ for clouds in layer m with tops exposed to space



- achieving an accurate distribution of cloudtops exposed to space appears doable

(given *correct* cloud fraction profiles and effective decorrelation lengths)

500 km cross-sections



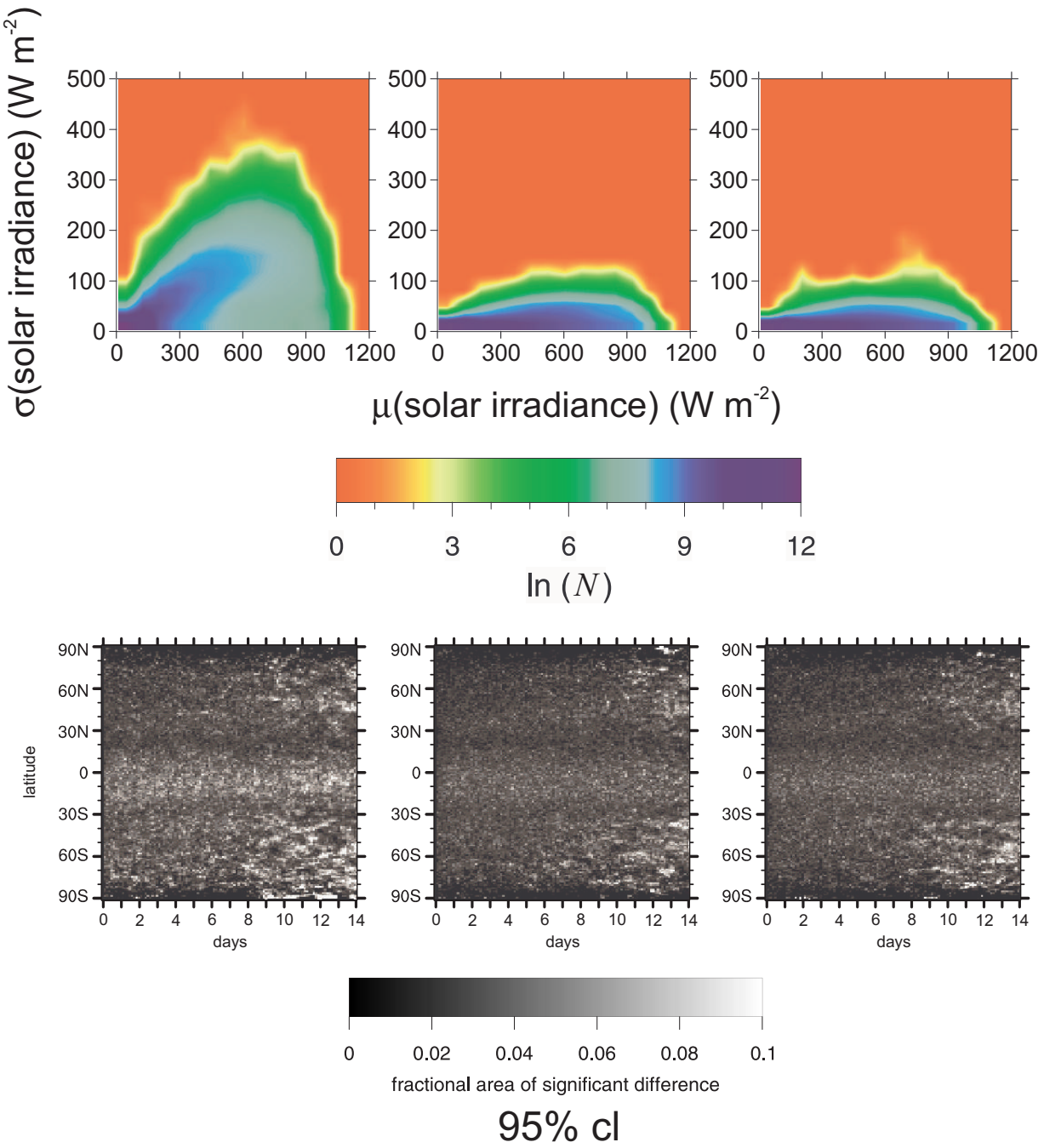
- abundant (but significant?) random noise due to global setting

  - max-rand scheme has this *noise* too

- is it necessary to reduce variance?... cf. McICA

500 km cross-sections

ECMWF


σ(solar irradiance) (W m-2)
500
400
300
200
100
0
0 300 600 900 1200
μ(solar irradiance) (W m-2)
0 3 6 9 12
ln (N)
90N
60N
30N
0
30S
60S
90S
latitude
0 2 4 6 8 10 12 14
days
0 0.02 0.04 0.06 0.08 0.1
fractional area of significant difference
95% cl

Radiative Sensitivity for Overlap

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$$\frac{\partial F_{\mathrm{ICA}}}{\partial \mathcal{L}_{cf}} \simeq CRE\frac{\partial \ln \widehat{C}}{\partial \mathcal{L}_{cf}} + \widehat{C}\left[\underbrace{\frac{\partial F_{\mathrm{cld}}}{\partial \overline{\tau}}\frac{\partial \overline{\tau}}{\partial \mathcal{L}_{cf}}}_{<0} + \underbrace{\frac{\partial F_{\mathrm{cld}}}{\partial \sigma_\tau}\frac{\partial \sigma_\tau}{\partial \mathcal{L}_{cf}}}_{\sim O(0)} + \cdots\right]$$

$$\begin{aligned}\left\langle\frac{\partial F_{\mathrm{ICA}}}{\partial \mathcal{L}_{cf}}\right\rangle &\simeq \langle CRE\rangle\left\langle\frac{\partial \ln \widehat{C}}{\partial \mathcal{L}_{cf}}\right\rangle - O(\lesssim 1)\\ &\simeq \left(-45\ \mathrm{Wm^{-2}}\right)\left(-0.08\ \mathrm{km^{-1}}\right) - O(\lesssim 1)\\ &\simeq 3\ \mathrm{Wm^{-2}\ km^{-1}}\end{aligned}$$

Radiative Sensitivity for Overlap

- to what extent is TOA radiation affected by overlap?...

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(LW is at least ~3 times smaller)

Conclusions + Recommendations

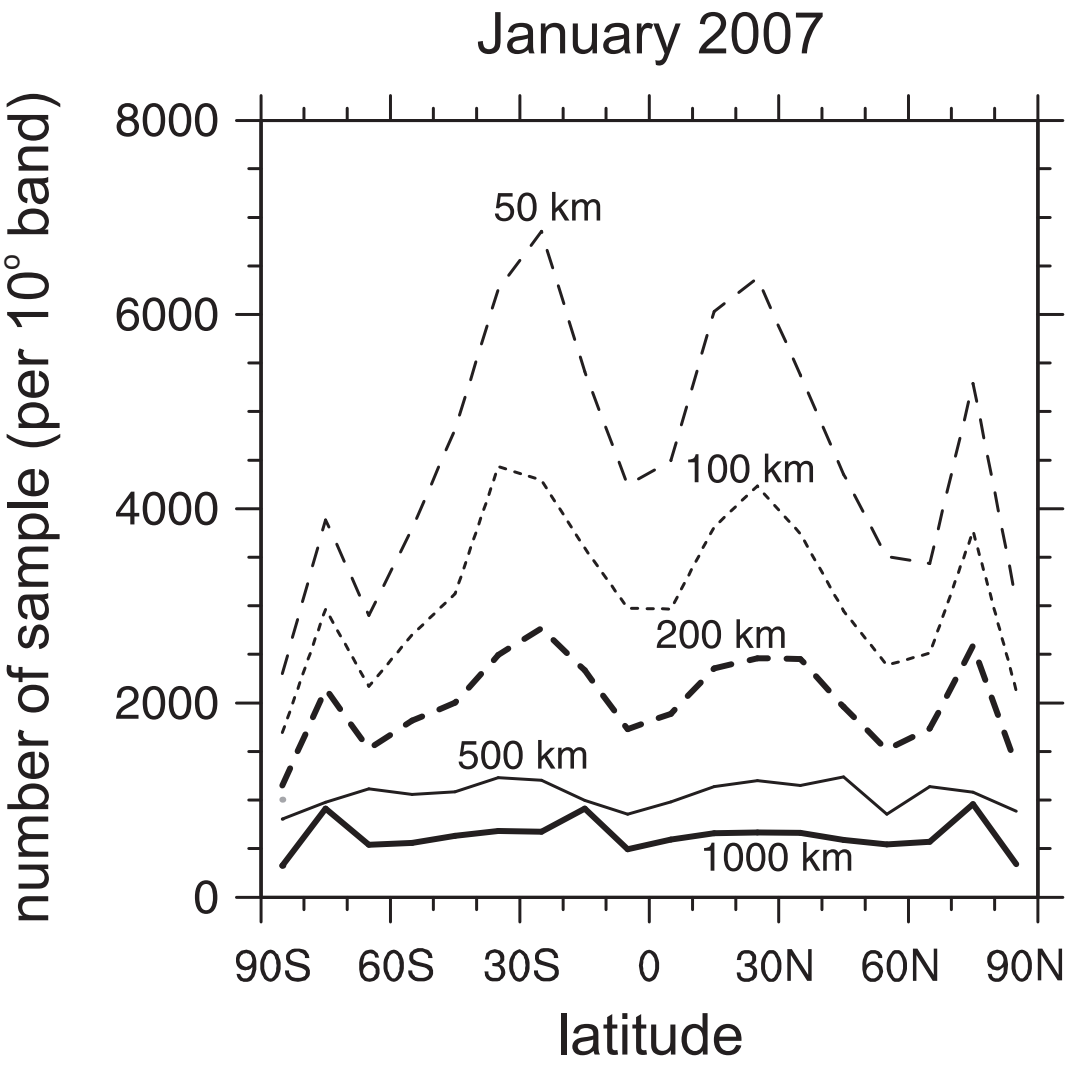
- 2 months of overlap analyses... more is needed
- bring in additional data (e.g., ECMWF)
- is $\mathcal{L}^*_{cf}$ sufficient?

  - can it be as simple as a few judicious settings based on local conditions?

- assess GCMs recognizing

$$F_{\mathrm{ICA}} = (1 - \widehat{C})F\left(0\right) + \sum_{m=1}^{M} \varepsilon_m \int_0^{\infty} \widehat{p}_m(\tau) F(\tau)\, d\tau$$

- if these are correct, so too is overlap, and your radiation budget


January 2007
number of sample (per 10° band)
8000
6000
4000
2000
0
50 km
100 km
200 km
500 km
1000 km
90S
60S
30S
0
30N
60N
90N
latitude